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Canada/NB MDA Project on Mine Shaft Rope Testing; Testing of 1 7/8 in., 34×7, NR, T.R. (our rope #12)

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CANADA/NB MDA PROJECT ON MINE SHAFT ROPE TESTING; TESTING OF $1\frac{7}{8}$ IN., 34 × 7, NR, T.R. (OUR ROPE #12)

by

L.B. Geller*, D. Poffenroth†, J.E. Udd**, and D. Hutchinson††

ABSTRACT

In this report the authors analyse the test-results obtained, non-destructively, on a $1\frac{7}{8}$ in., 34 × 7, non-rotating (NR) tail-rope (T.R.). The rope was only examined in situ, as part of CANMET's project to comparatively evaluate the performance of a range of EM wire-rope testers. This is the first time that a project of this magnitude and diversity has been undertaken.

The tail-rope in question (designated #PB3 at the mine) was tested by mistake, instead of its companion rope (designated #PB2). Within the context of CANMET's present project it was intended to only test ropes that were just about ready to be discarded — i.e., that were in a bad, or very bad, condition — in order that the ropes might be tested both in situ and, soon afterwards, also on the shop-floor. In this context the condition of rope #PB3 was too good.

Even though we only obtained in situ test results on a relatively new rope, these are of interest because of the unacceptably wide difference between the reported results. In this paper the authors examine the reasons for this discrepancy.

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Keywords: New Brunswick; Mineral Development Agreement; Wire-ropes; Non-destructive-testing; Electro-magnetic instruments; Spin-resistant ropes

PROJET EDM CANADA/NB SUR L'ESSAI DES CÂBLES DE PUITS DE MINE; ESSAI D'UN C.Q. A.G., 34 X 2, DE 1 7/8 PO (CÂBLE NO 12)

par

L.B. Geller*, D. Poffenroth**, J.E. Udd*** et D. Hutchinson****

RÉSUMÉ

Dans ce rapport, les auteurs analyse les résultats d'un essai non destructif d'un câble de queue (C.Q.) antigiratoire (A.G.), 34 x 7, de 1 7/8 po. Le câble n'a été examiné que sur place dans le cadre d'un projet de CANMET visant à comparer les rendements de divers instruments ÉM à câble métallique. C'est la première fois qu'un projet de cette envergure et de cette diversité est réalisé.

Le câble de queue en question (désigné no PB3 à la mine) a été contrôlé par erreur au lieu de son voisin (désigné no PB2). Le projet de CANMET ne visait qu'à contrôler des câbles approchant la fin de leur vie utile, c.-à-d. en mauvais ou très mauvais état, dans le but de contrôler les câbles sur place et, peu après, en atelier. Dans ce contexte, le câble no PB3 était en trop bon état.

Même si les seuls résultats obtenus proviennent d'un essai sur place d'un câble relativement neuf, ils sont intéressants à cause des écarts anormalement grands entre les résultats. Dans le présent exposé, les auteurs examinent les causes de ces écarts.

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Mots clés: Nouveau-Brunswick; Entente de développement minéral; câcles métalliques; essai non destructif; instruments électromagnétiques; câbles antigiratoires

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BACKGROUND

The results described in this report constitute an integral part of the contracted phase of CANMET's project, undertaken in 1986 in response to requests by both the mining industry and the mine regulatory authorities. The basic project objectives specified that the continuing rope failures, or near failures — occurring despite mandatory wire-rope examinations with electro-magnetic (EM) instruments at regular intervals — be documented, examined, analysed, and clarified. This is the first time that a project of this scope and depth has been undertaken, anywhere.

CANMET's work included both in-house and contracted work phases. The in-house phase resulted in a range of conclusions and recommendations, reported elsewhere (1, 2, 3, 4). We are now in the process of reporting the results obtained during the contracted project-phase, which included a series of in situ and shop-floor tests. The first five reports in this series were published in February, May, June, and July, 1990 (5, 6, 7, 8, 9). This is the sixth such report. More are to follow.

ROPE DETAILS

The rope on which this report is based (referred to as "our rope #12") was designated as the #PB3 tail-rope in Shaft #1 of Potash Company of America's mine at Sussex, New Brunswick. It was manufactured by Trefileries & Cableries Chiers Chatillon Gorcy, at Bourg en Bresse, in France. Its reel number was RL1-P8656-34B107 (rope #843230-1). It measured $1\frac{7}{8}$ in. diam × 2,258 ft.

It was of a 34 × 7 non-rotating (NR) construction (34 × 0.096 in. inner wires; 204 × 0.091 in. outer wires), with a mass of 6.236 lb/ft; right-Langs-lay; bright steel. Its breaking strength was 284,777 lb, as established by TECNOR of Bourg en Bresse on 19.9.85. It was purchased on 5.11.85, installed on 9.3.88, and removed on 11.4.90 (25 months of service).

Its two $1\frac{7}{8}$ in., 34 × 7, companion tail-ropes (designated as #PB1 and #PB2) — in use at the time of our own 20.10.88 field testing — were installed on 8.3.88 and 9.4.87, respectively.

Unfortunately, our own tests on 20.10.88 were performed, by mistake, on rope PB3, instead of on rope PB2, as had been intended. Although PB3 had, at that time, been in use for only seven months, and was, consequently, nowhere near discard-condition, it is of interest to discuss our in situ test results, because of the unacceptably

wide difference between those reported by the Magnograph, and those by the LMA-250 operator. No EM testing had been performed on rope PB3 prior to our own tests. No shop-floor testing could be performed on PB3 by us, during the lifetime of our current project.

IN SITU TEST RESULTS — AS REPORTED

The Magnograph data

Testing was performed on 20.10.88 on a reported rope length of some 750 yards (2,250 ft). A copy of the instrument chart, as submitted by the operator with his report #88-525C, is reproduced in Fig. 1a. On it we note the operator's marking of 6.5% LMA. In the written report the operator noted a maximum loss-of-metallic-area (LMA_{max}) of 8.0%, some 10-50 yards from the skip-attachment. Moreover, the operator's report mentions a 1.0% LMA at the 221 yard 'broken wire' location, and a 0.75% LMA at the 250 yard 'broken wire' location. The operator marked the location of these conspicuous wire-breaks on the Local Fault (LF) instrument chart (Fig. 1a). Their distance from each other was 87 ft.

Finally, the operator also submitted loss-of-breaking-strength (LBS) estimates for the 221 yard and 50 yard locations from the start of the test. These were some 3.5% (report #89-017) and 10.0% (report #88-525C), respectively.

The LMA-250 data

On the same date testing was also performed with an LMA-250 instrument on a reported rope length of some 1,970 ft. A copy of the instrument chart, as submitted to us by the operator, is reproduced in Fig. 2. On it the operator marked an LMA_{max} of 3.0% at 160 ft, and again at 1,230 ft from the start of the test. The two broken-wire rope segments — noted on the Magnograph chart (Fig. 1a) — are conspicuous on both the LMA and the LF chart traces of the LMA-250 instrument as well, around the 1,230 ft and 1,315 ft locations. Their distance from each other was 85 ft, i.e., remarkably close to the one measured on the Magnograph chart. Direction of rope travel through the LMA-250 was opposite to that through the Magnograph. The reported %LMA chart-readings at these wire-breaks are 3.0% and 2.0% (Fig. 2).

The Rotesco AC data

New Brunswick provincial regulations at the time of the tests stipulated that initial EM testing of tail-ropes be performed after 12 months of rope operation, and then at intervals sufficient to ensure safety (1). Hence, there was no routine EM testing of tail-rope PB3 prior to our own tests. Subsequently, the first mandatory test was performed on 21.3.89, with a Rotesco AC instrument. This was designated as test #AMM-44. The rope length tested was some 2,052 ft. The report refers to an LBS_{max} of 3.5% between 125 ft and 180 ft from test-start below the #2 compartment skip. With a factor of 1.7, as we used before elsewhere (9), this translates into an LMA_{max} of some 2.1%. Estimated localised strength losses of some 3.0% were also reported between 30 ft and 80 ft; 85 ft and 95 ft; 1,180 ft and 1,185 ft; 1,255 ft and 1,265 ft; and between 1,720 ft and 1,735 ft from test start below the #2 compartment skip, as well as between 130 ft and 150 ft below the #1 compartment skip.

The two conspicuously broken wires were noted at about 1,185 ft and 1,258 ft (a distance of 73 ft) from test-start. Their LMA chart-readings are in the order of 2.2% and 2.0%. Direction of rope travel was the same as it was during the LMA-250 test. We reproduce the operator's original strip-chart in Fig. $3a_1$. In Fig. $3a_2$ we reproduce this chart as respliced and marked by us.

The next routine (and seemingly last before discard) test on rope PB3, also with a Rotesco AC instrument, was performed on 26.9.89. This was designated as test #AMM-87. Its report refers to an LBS_{max} of 9.0% (i.e., to a 5.3% LMA_{max} with a factor of 1.7) between 1,085 ft and 1,095 ft, as well as between 1,175 ft and 1,185 ft below the #2 compartment skip (i.e., at the two conspicuous wire-breaks). Estimated strength losses of 7.0% to 8.0% were also reported between 35 and 45 ft; 55 and 65 ft; 90 and 95 ft; 125 and 145 ft; and 115 and 175 ft below the #2 compartment skip. Along the first 20 ft; 95 to 105 ft; 145 to 155 ft; and 235 to 250 ft below the #1 compartment skip an estimated LBS of some 6.0% to 8.0% was reported. We reproduce the operator's original strip-chart in Fig. $3a_3$. In Fig. $3a_4$ this chart is shown as respliced and marked by us.

We also have information about the present PB3 rope's: (a) predecessor , and (b) companion tail-rope (#PB2). These results are of interest, because they supplement our knowledge of local mine-shaft conditions. Both ropes were of the same construction and size as the current rope #PB3.

The previous rope PB3 was installed on 19.10.85, and removed on 9.3.88 (29 months of sevice). The last routine EM test on it was performed with a Rotesco AC

instrument on 1.3.88 (test #WMP-36). The rope length tested was some 1,910 ft. The report referred to an LBS_{max} of about 17.0% between 1,900 ft and 1,910 ft — and some 15.0% LBS between 760 ft and 770 ft — from the test-start below the #2 compartment skip. A copy of the relevant instrument-chart, with the rope rising, is reproduced in Fig. $3b_1$. The LMA_{max} is 5.5% at 750 ft from test-start, and at the 1,910 ft rope-end.

As may be seen, the recorder-pen went off-scale at the 750 ft and 1,910 ft chart locations, with the 5.0% Full Scale (F.S.) sensitivity setting (Fig. $3b_1$). Therefore, a second test-run was undertaken, with a sensitivity setting of 10.0% F.S. and with the rope descending (Fig. $3b_2$). Now the LMA_{max} value was seen to be some 10.0% at test-start and 7.9% at 1,090 ft.

In Figures $3c_1$ and $3c_2$ we reproduce the operator's strip-charts (Figures $3b_1$ and $3b_2$), as re-aligned and marked by us for a clearer overview of rope conditions.

The companion rope PB2 was installed on 9.4.87. It is currently in use. It was first routinely tested (Fig. 3d) with a Rotesco AC instrument on 1.3.88 (test #WMP-37). The reported LBS_{max} was 2.0%, some 100-110 ft below the #2 compartment skip. The next routine test, again with a Rotesco AC tester (Fig. 3e) was performed on 21.3.89 (test #AMM43). We have reproduced the operator's original strip-chart as Fig. $3e_1$. In Fig. $3e_2$ we reproduce this chart as respliced and marked by us for a clearer overview of rope conditions.

Now, just about one year after the first test, the reported LBS_{max} was 14.0%, between 210 ft and 220 ft below the #2 compartment skip, with a general strength-loss in the order of 8.0%–10.0% between 60 ft and 200 ft below this skip. This is a rather spectacular increase of some 600% in the estimated maximum LBS. The corresponding LMA increase, on the basis of actual chart-readings, is from 1.2% to 7.3%. A localized 8.0% LBS was also reported between 95 ft and 105 ft, and between 130 ft and 140 ft below the #1 compartment skip. Over the remainder of the rope tested the reported LBS did not exceed 8.0% to 9.0%.

It is significant that a conspicuous major LMA location was reported, consistently, some 210–220 ft below the #2 compartment skip in rope #PB2 (Figures 3d and 3e), as well as in rope #PB3 (Figures 3a and 3b). Signs of such a developing fault in this general area appear in the LMA-250 test-chart (Fig. 2). Conditions on the Magnograph operator's chart (Fig. 1a) are less clear-cut.

IN SITU TEST RESULTS — AS REVIEWED

The Magnograph data

On comparing the operator's reported LMA_{max} chart reading of 8.0% (at 10-50 yards from skip attachment) with the corresponding LMA-250 and Rotesco AC chart-readings, problems arise. These include: (a) the spliced-on chart section, marked along its edge with a length designation of 662-750 yards, and with 'overlap' at its point of attachment to the main chart-segment. This segment's origin, and the method of its alignment with the main instrument chart, are both unclear; (b) the sudden 5.0% step in the LMA chart-trace at the 92 yard location. There is no corresponding perturbation on the LF chart-trace. Nor anything like it sems to be recorded on the LMA-250 instrument chart.

The operator made no mention of where the 100% reference-level had been placed, or what the LMA sensitivity setting had been. From the reported 8.0% LMA_{max}, and 6.5% chart-marking, we conclude that: (1) the sensitivity used was, as usual for this operator, 2.5%LMA per major chart-division, and (2) the 100% reference-level was around the 339 yard chart location.

In an attempt to clarify the aforementioned questionable report-details, we obtained a copy of the operator's magnetic test-tape, and produced therefrom our own chart print-out (Fig. 1b). On comparing Figures 1a and 1b we noted some similarities, and some differences, between the two. These included the following: (a) the overall tested rope length was 1,986 ft per Fig. 1b, vs 2,250 ft per Fig. 1a — the difference being, approximately, the 260–270 ft chart segment spliced on to the main chart in Fig. 1a, (b) the main 662 yard (1,986 ft) chart length itself, without the extra spliced segment and without the spurious LMA-step, is comparable with the LMA-250's 1,972 ft chart length, and is in line with the Rotesco AC's 2,052 ft tested rope-length, (c) the spurious 5.0% LMA-step is present in both Figures 1a and 1b (in each case at about 92 yards from test-start), (d) the two broken wire locations are 87 ft apart in both figures, (e) the first of the two broken wire locations is some 214 yards from test-start in both Figures 1a and 1b, (f) we were unable to clearly determine the exact origin of the operator's spliced-on 662-750 yard (264 ft) long chart-segment, or to settle the question as to which rope-end this chart-segment should be attached to, (g) we are further examining the latter question.

From the provincial mine-inspector's report we noted that, about $1\frac{1}{2}$ hr before the Fig. 1a 'second' Magnograph test-run, there had been an earlier test run as well

(Fig. 1c). As may be noted from the operator's comments on Fig. 1c, this run had to be repeated on the grounds that dampness had affected the cable contacts in the sensor head. The rope travelled in the same direction during both the first and second Magnograph test-runs.

We note that the recorder-pen went off-scale at exactly the same chart-location during the first test (Fig. 1c), as where we find the spurious 5.0% LMA-step on the second test-run (Fig. 1a). Also, no corresponding perturbation exists at this spot on either of the two LF chart-traces. From a comparison of these figures we conclude: (a) that some unexplained rope anomaly caused the 5.0% LMA-step in Fig. 1a (unless the operator used two instrument set-ups), and (b) that the recorder-pen remained off-scale along the 92-662 yard rope section (Fig. 1c) not because of some malfunctioning cable-connection, but because once the 5.0% LMA-step had pushed the pen off-scale, the rope conditions continued to be so much better (than along the initial 0-92 yards) that all events along the 92-662 yard section were, in actual fact, duly recorded on the test-tape, while being off the strip-chart scale.

We were not present during the tests on 20.10.88, and do not know exactly how the operators set up their tests. We cannot, therefore, offer a definitive explanation for the origin of the abovementioned 5.0% LMA-step. We do, however, note that the situation very closely resembles the one described in the Magnograph's "Operating and Maintenance Manual", section 4.7, on "Rope Magnetization". In it conditions are examined that arise when rope tests are carried out in two parts, due to access problems in the field. Unless due care is taken on such occasions to properly re-align the sensing head when setting-up for the second rope section, a major LMA zero-shift will occur where the two tests ultimately meet, without a concurrent reaction on the LF-trace.

Is this what happened? The 5.0% LMA-step occurs, both on the 'second' (Fig. 1a) and 'first' (Fig. 1c) Magnograph strip-charts at exactly the same spot — namely at 92 yards from test-start — although there was another (the LMA-250) test-run in between these two Magnograph tests. These 92 yards on the main-chart almost exactly equal the 87 yards of the spliced-on chart-segment. Is the latter segment, therefore, a rerun over the main chart's 0–92 yard chart-length? Certainly, in both the LMA-250 and Rotesco AC strip-charts (Figures 2 and 3a) the two conspicuous wire-breaks are at about the same distance from the #1 compartment skip rope-end (some 660–860 ft) as they are on the Magnograph-chart (Fig. 1a). But, in that case, there should not be a difference between the Magnograph's 662–749 yard, and the 0–92 yard, LMA chart-traces. And there is a difference. Also, if we replace the 0–92 yard main chart LMA trace with the 992–749 yard trace (Fig. $1d_1$) the LMA_{max} chart-reading in the first 200 ft of rope below the compartment #1 skip is 10.5%, rather than the equivalent

8.5% (Fig. $1d_2$) obtained when we attach the 662–749 yard chart segment to the other rope end. The latter %LMA value appears to be the more "acceptable" one.

As mentioned earlier, we are unable to definitely clarify this confused situation, especially since the 5.0% LMA-step does not seem to appear on the corresponding LMA-250 chart-segment.

The LMA-250 test was performed from 10.40–11.10 a.m. on 20.10.88, in between the two Magnograph tests which occurred at 9.50 a.m., and at 11.25 a.m. The rope travelled in opposite directions during the LMA-250 test, and the two Magnograph test-runs. Therefore, the 92 yard location on the Magnograph chart corresponds to some 1,702 ft on the LMA-250 chart.

The LMA-250 data

Rope-movement through the LMA-250 was in the opposite direction to what it was through the Magnograph. We disagree with the operator's choice of 100% reference-level at about the 380 ft chart-location (Fig. 2). On the operator's chart there is a somewhat "better" rope-section around the 1,930 ft location, although in practical terms the difference is negligible (some 0.5%). But even accepting the operator's choice of the 0% LMA level, the chart-readings at the two conspicuous wire-breaks (located at about 1,233 ft and 1,315 ft on his chart) should be 1.0% more than were marked.

We also question why the operator disregarded the very conspicuous worsening of rope conditions past the 1960-1970 ft mark. In this short rope segment we note a %LMA chart-reading of some 8.0%. We suggest that this should not have been ignored without detailed explanations. This is the same loss as can be read, at the same rope-end, off the Magnograph chart (Fig. 1d) — even if, on the latter chart, this LMA is obtained much more gradually, over a very much longer rope section. Perhaps, the LMA-250 operator omitted to set up for a second test-run, to examine the final rope section that is covered by the Magnograph's and Rotesco AC's spliced-on chart-segments? A considerable %LMA was, certainly, also observed by the Rotesco AC instrument (at the compartment #1 skip rope-end) both on the previously installed (Fig. 3c) and on the present PB3 ropes (Fig. 3a).

The Rotesco AC data

Rotesco AC results were obtained on 21.3.89 (Fig. $3a_1$) and on 26.9.89 (Fig. $3a_3$) — i.e., some 5 and 11 months later than our own Magnograph and LMA-250 results.

Interestingly the ratio of the estimated LBS_{max} values obtained on the basis of the 21.3.89 and 26.9.89 tests is 2.9, while that of the LMA_{max} chart-readings is 2.6. On 21.3.89 the rope had been in use for about one year. In Fig. 3d we show a record of rope #PB2 after one year of usage. Rope #PB3 seems to be deteriorating at the same rope locations, but at an even faster rate than its companion-rope #PB2. Even the deterioration-rate of the latter was seen to be quite worrisome (Fig. 3d vs Fig. 3e).

We agree with the reported chart-readings *per se*, but not necessarily with the quantitative values.

COMPARISON OF IN SITU CHART-READINGS

The characteristic rope sections upon which we can base a comparison of the EM testers used, are: (1) the 0–200 ft segments at the two rope-ends below the #1 and #2 compartment skips, and (2) at the two conspicuous broken-wire locations.

Such a comparison is presented in Table 1. Details of the different test set-ups are listed in Table 2.

SUMMARY

A mistake was made in field-testing tail-rope #PB3 (our rope #12) instead of tail-rope #PB2. Rope #12 was, therefore, in a much better condition than desirable for purposes of the present project. Consequently, the rope could not be removed for shop-floor testing during the lifetime of our project. All the same, the reported in situ results are of considerable interest because of the unacceptably large difference between them.

As noted, the tests in question were performed on a relatively new rope. No difficulty was, therefore, expected in obtaining congruent and reliable results. Unfortunately, this proved not to be the case. The reported LMA_{max} values differ by more than 100% (Table 1). So do the estimated LBS_{max} values (10.0% by the Magnograph operator vs 3.5% by the Rotesco AC operator).

Despite our in-depth review of the strip-charts submitted to us, we are unable to definitely say which %LMA results are closest to the "true" ones. We suspect that the Rotesco AC values are too low, due to this instrument's relatively weak magnetic-field, and to the relatively large ($1\frac{7}{8}$ in.) rope size being examined. In this context we note the low Rotesco AC chart-readings at the two conspicuous wire-break rope-locations,

where the much larger Magnograph and LMA-250 chart-readings are in fair agreement (Table 1). Elsewhere, however, the results are confusing. On the basis of information submitted to us the "true" LMA_{max} could, possibly, be in the order of 8.0% to 9.0%.

We have detailed a number of errors that were, in our opinion, committed by the operators.

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APPENDIX

Tables 1 and 2

as well as Figures 1 to 3, inclusive

Table 1

LMA_{max} chart-readings; in situ tests of T.R. #PB3

Rope segment*	LMA-250 on 20.10.88		Magnograph on 20.10.88		Rotesco AC			
					on 1.3.88		on 26.9.89	
	Fig. 2 α	Fig. 2 β	Fig. 1a α	Fig. $1d_2$ β	Fig. $3a_1$ α	Fig. $3a_2$ β	Fig. $3a_3$ α	Fig. $3a_4$ β
#1	3.0%	3.5%	—	3.0%	2.1%	3.0%	4.7%	5.1%
#2	3.0%	4.5%	0.8%	4.6%	1.8%	2.2%	5.3%	4.5%
#3	2.0%	3.5%	1.0%	3.9%	1.8%	2.0%	5.3%	4.2%
#4	—	9.5%	8.0%; 6.5%**	8.3%; 8.5%**	1.8%	3.2%	4.7%	3.9%
Rope-length, per strip-chart	1,972 ft		1,986 ft		2,052 ft		1,880 ft	

α = as reported; β = as reviewed

*: #1= 0-200 ft rope end below #2 compartment skip

#2= broken wire, some 1,315 ft from #2 compartment skip rope end

#3= broken wire, some 1,230 ft from #2 compartment skip rope end

#4= 0-200 ft rope end below #1 compartment skip

**: uncertain rope-segment location in spliced-on chart-section

Table 2

Details of EM testing of the 1 7/8 in., 34×7, NR, T.R. (#PB3)

Item No.	Test Instr.	Test No.	Test date	Test location	Instr. operator*
1	Rotesco AC	WMP-36	1.3.88**	in situ	(1)
2	Rotesco AC	AMM-44	21.3.89	in situ	(1)
3	LMA-250	—	20.10.88	in situ	(3)
4	Magnograph	88-525C	20.10.88	in situ	(2)

*: (1) and (3) instrument maker and service company
(2) service company

**: in use prior to present #PB3 (our rope #12)

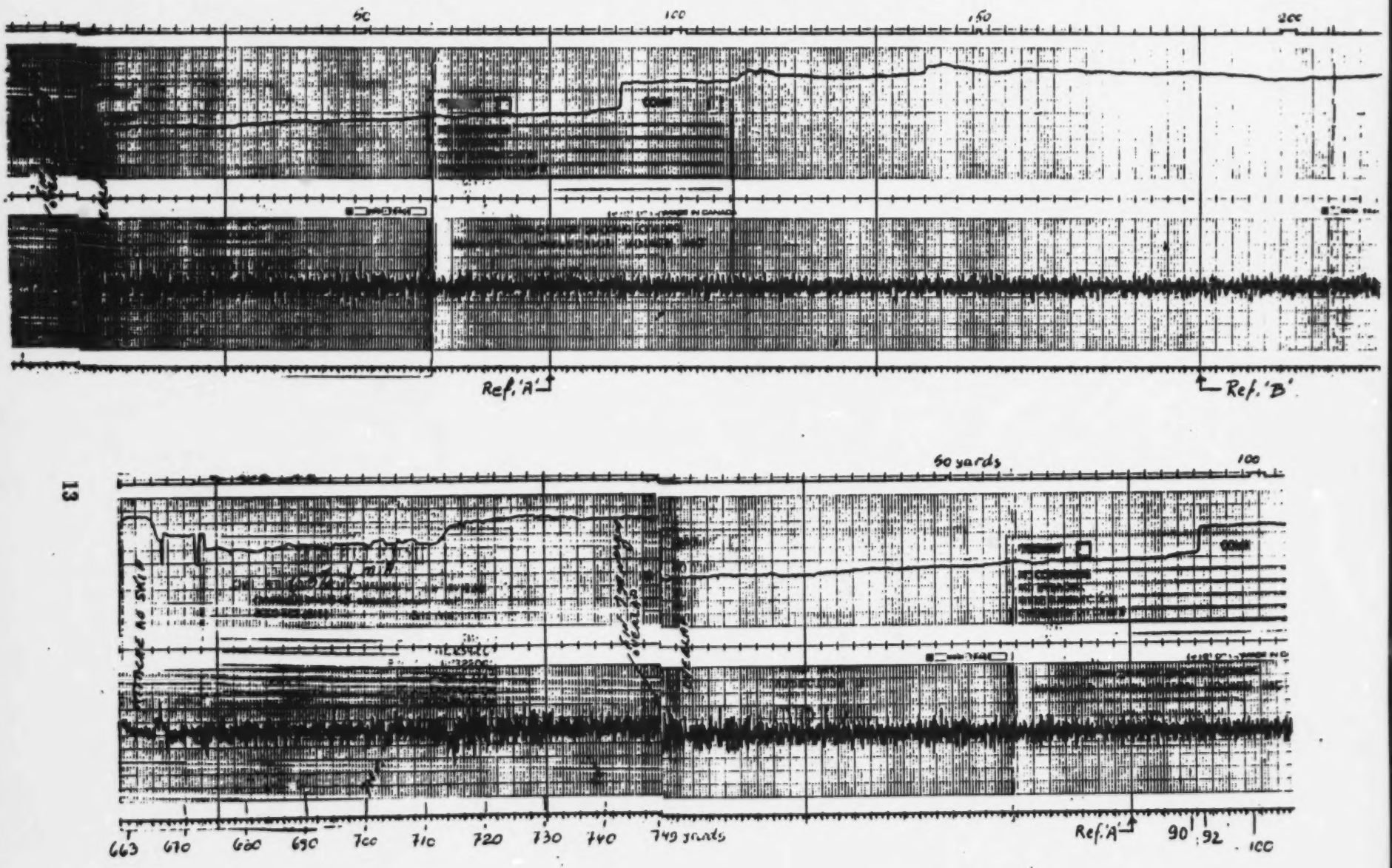

Fig. 1a — Rope PB3; 20.10.88 'second' Magnograph in situ test: operator's original strip-chart

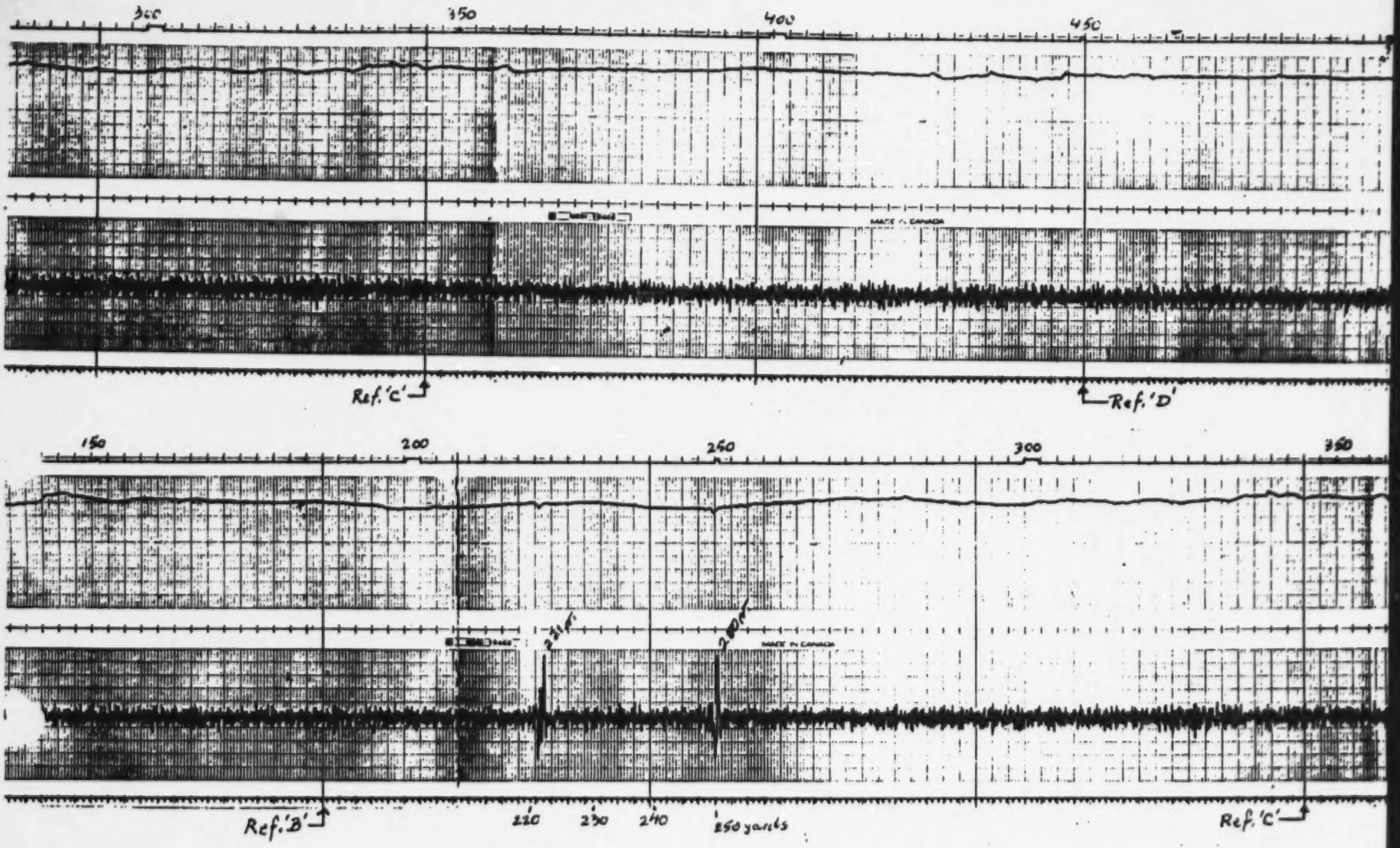

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Fig. 1a (continued) — Rope PB3; 20.10.88 'second' Magnograph in situ test: operator's original strip-chart

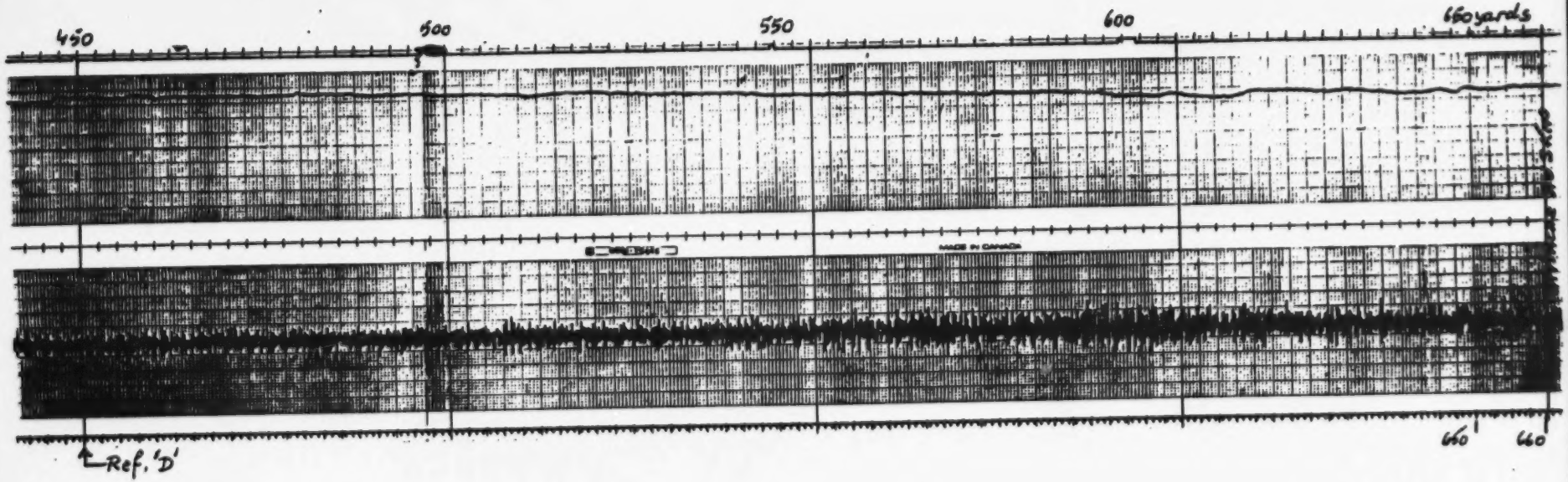

Fig. 1a (continued) — Rope PB3; 20.10.88 'second' Magnograph in situ test: operator's original strip-chart

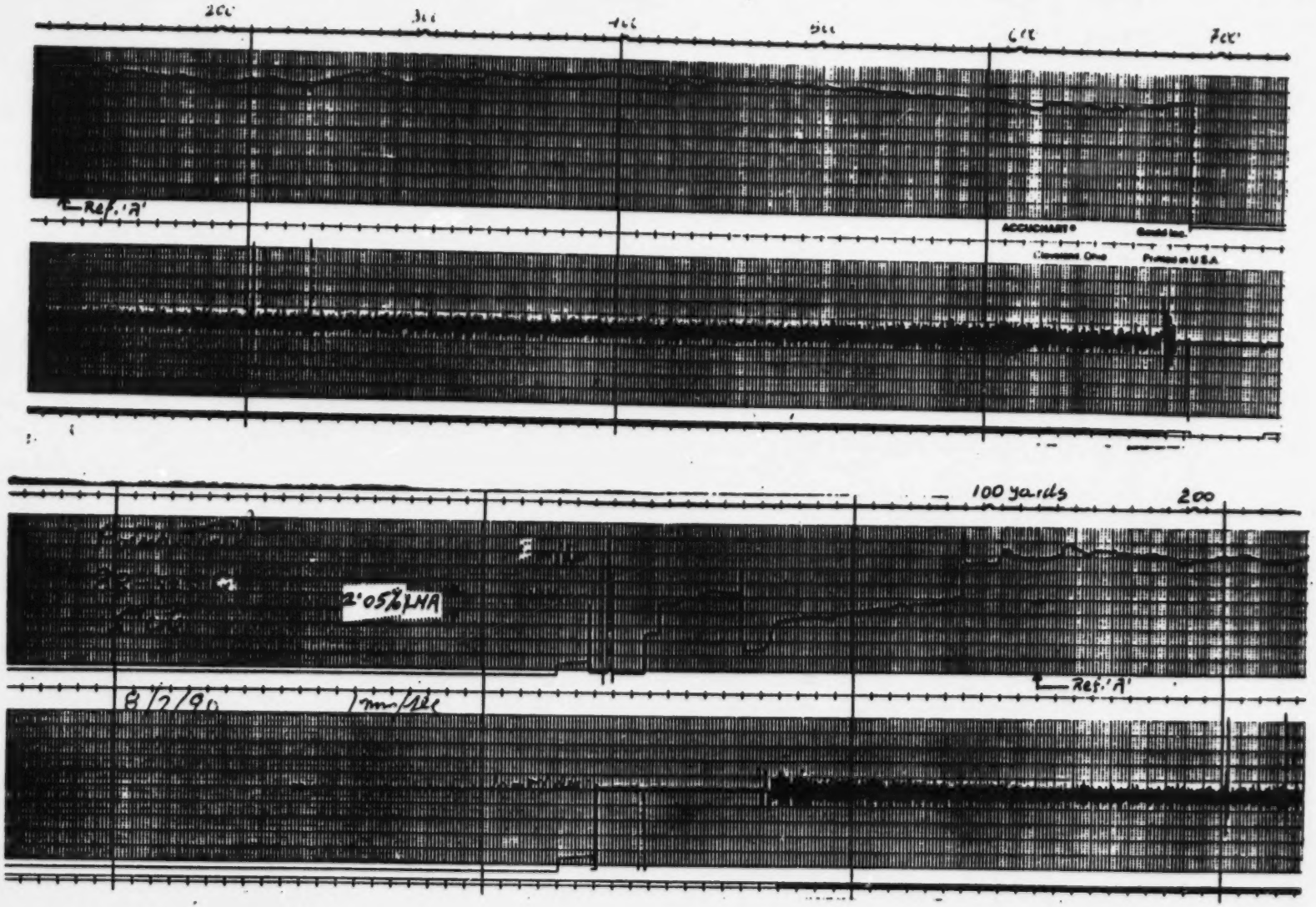

Fig. 1b — Rope PB3; 20.10.88 'second' Magnograph in situ test: authors' print-out from operator's test-tape

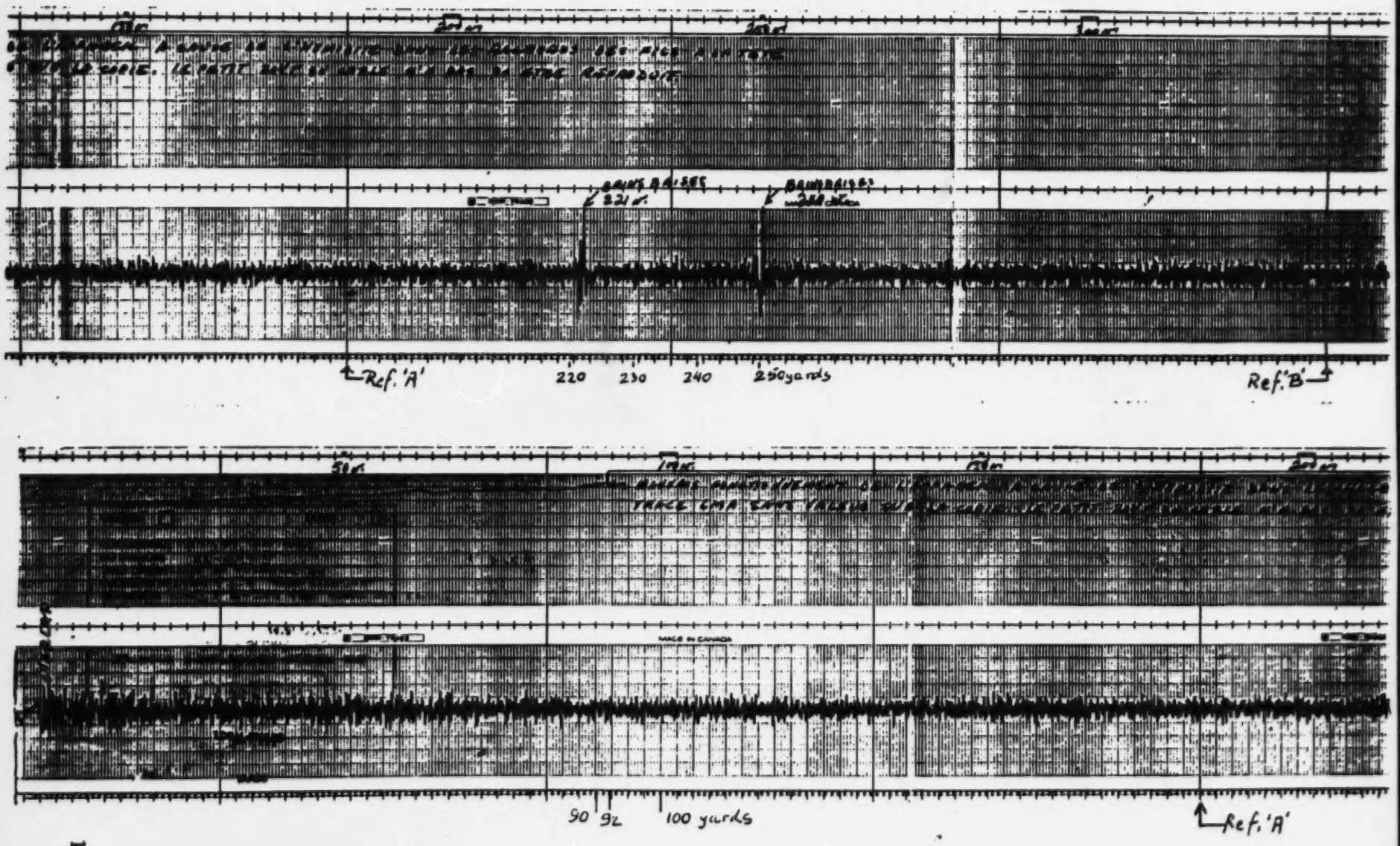

Fig. 1c — Rope PB3; 20.10.88 'first' Magnograph in situ test: operator's original strip-chart

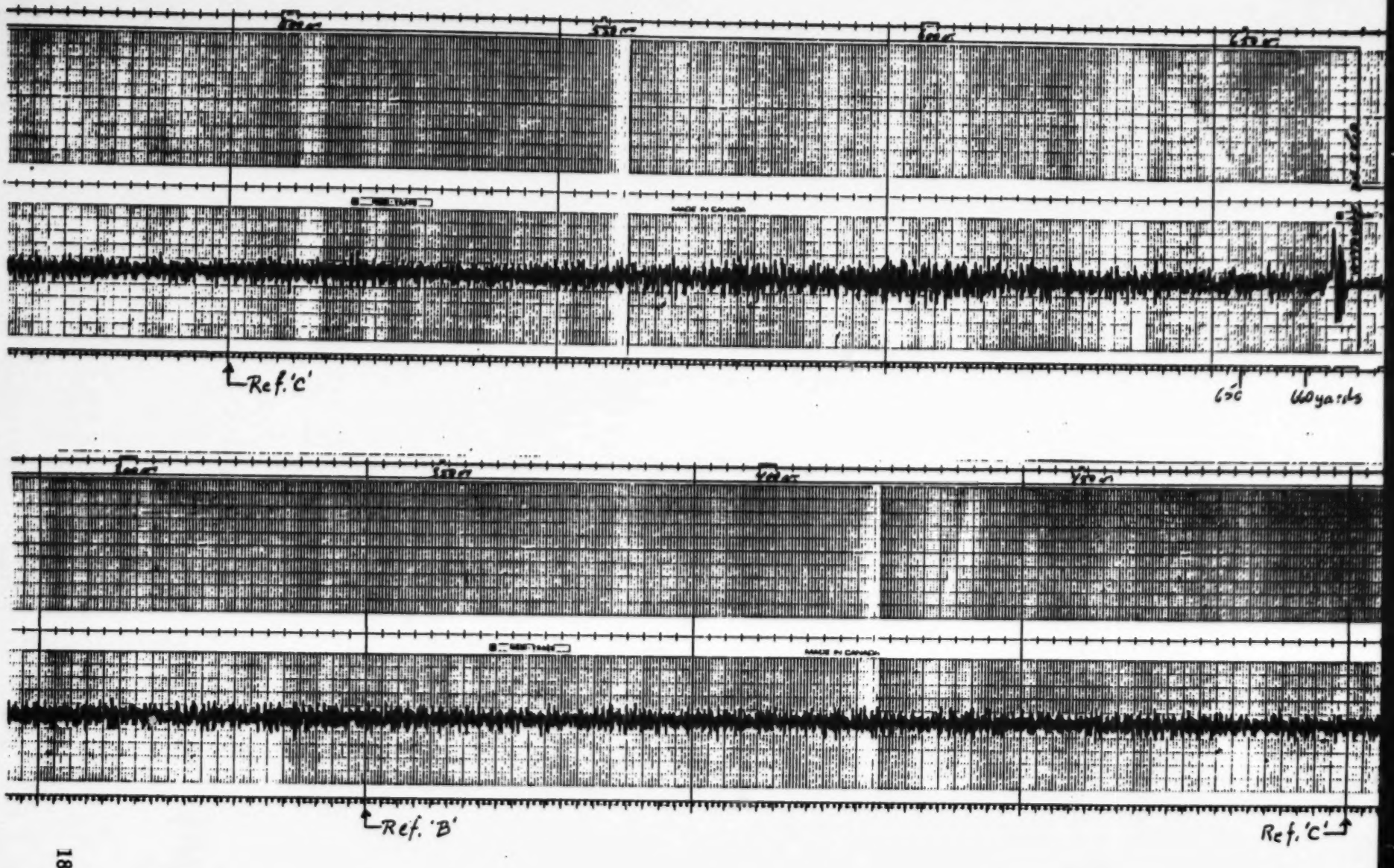

Fig. 1c (continued) — Rope PB3; 20.10.88 'first' Magnograph in situ test: operator's original strip-chart

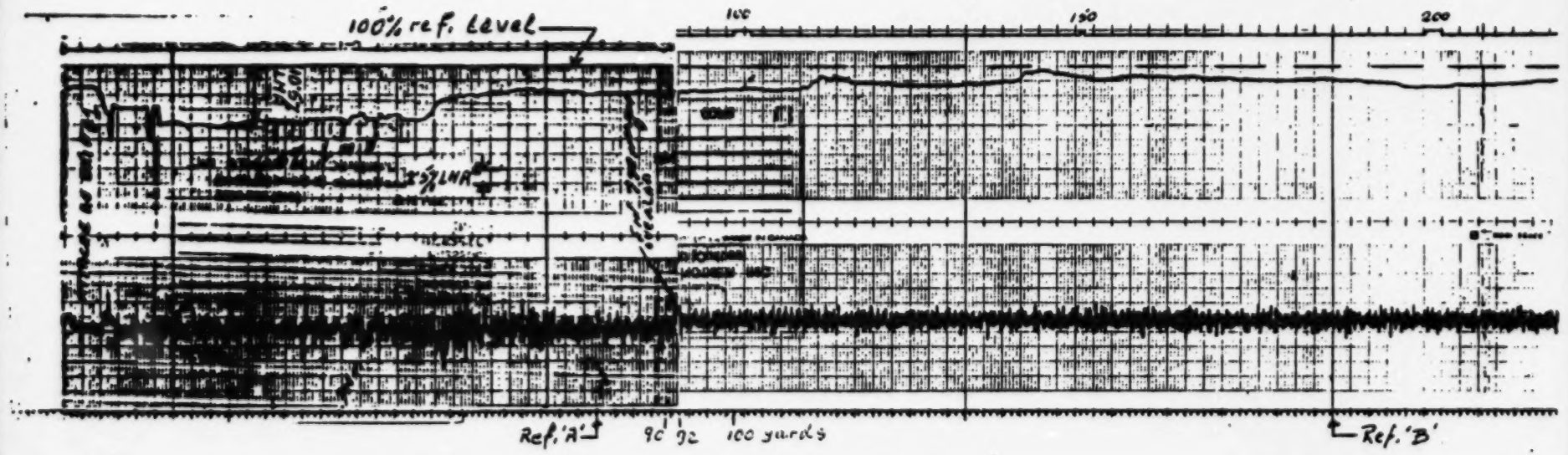

Fig. 1d$_1$ — Rope PB3; 20.10.88 'second' Magnograph in situ test: respliced and marked by authors (662–749 yard segment at compartment #1 skip rope-end)

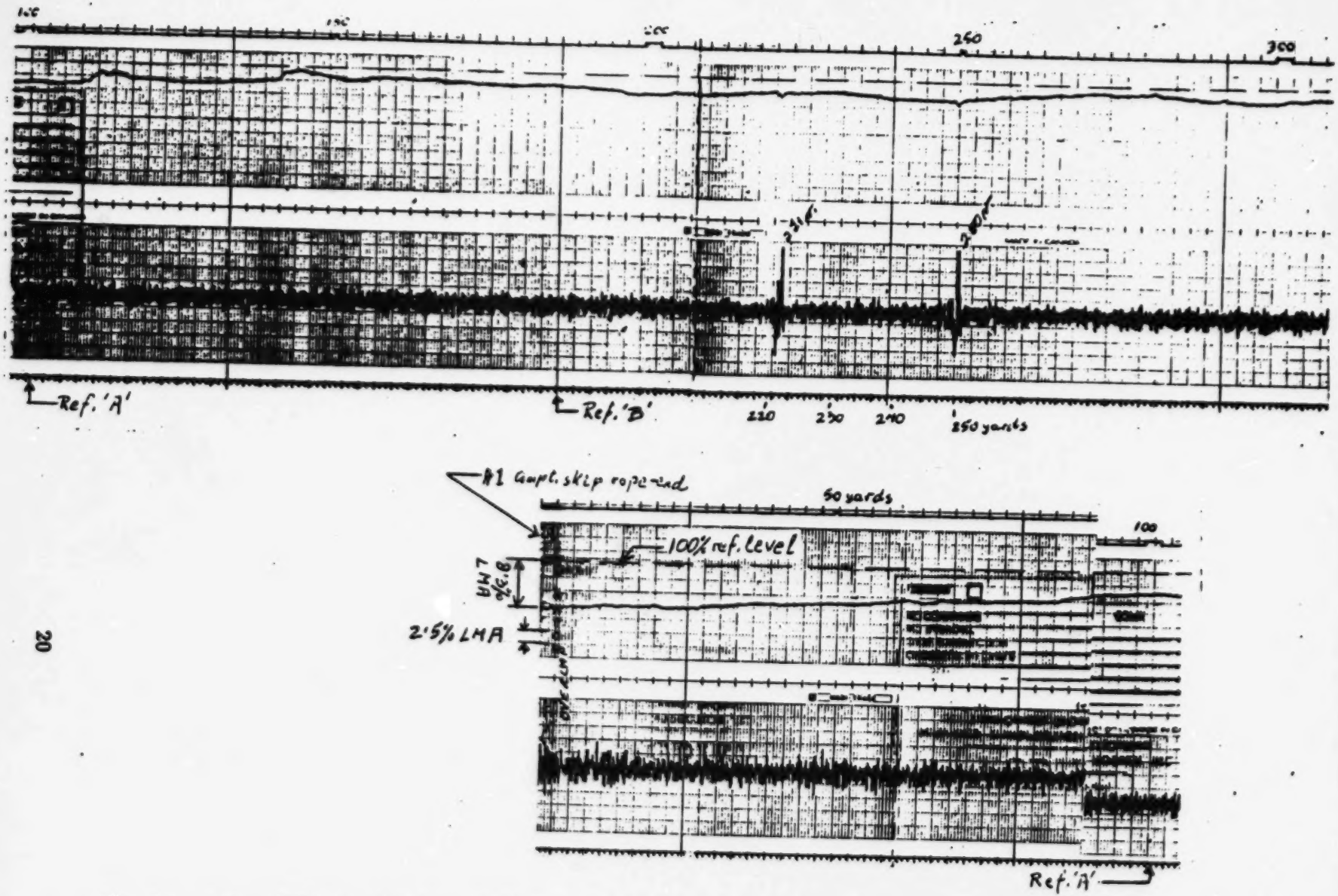

Fig. $1d_2$ — Rope PB3; 20.10.88 'second' Magnograph in situ test: chart respliced and marked by authors (662–749 yard segment at compartment #2 skip rope-end)

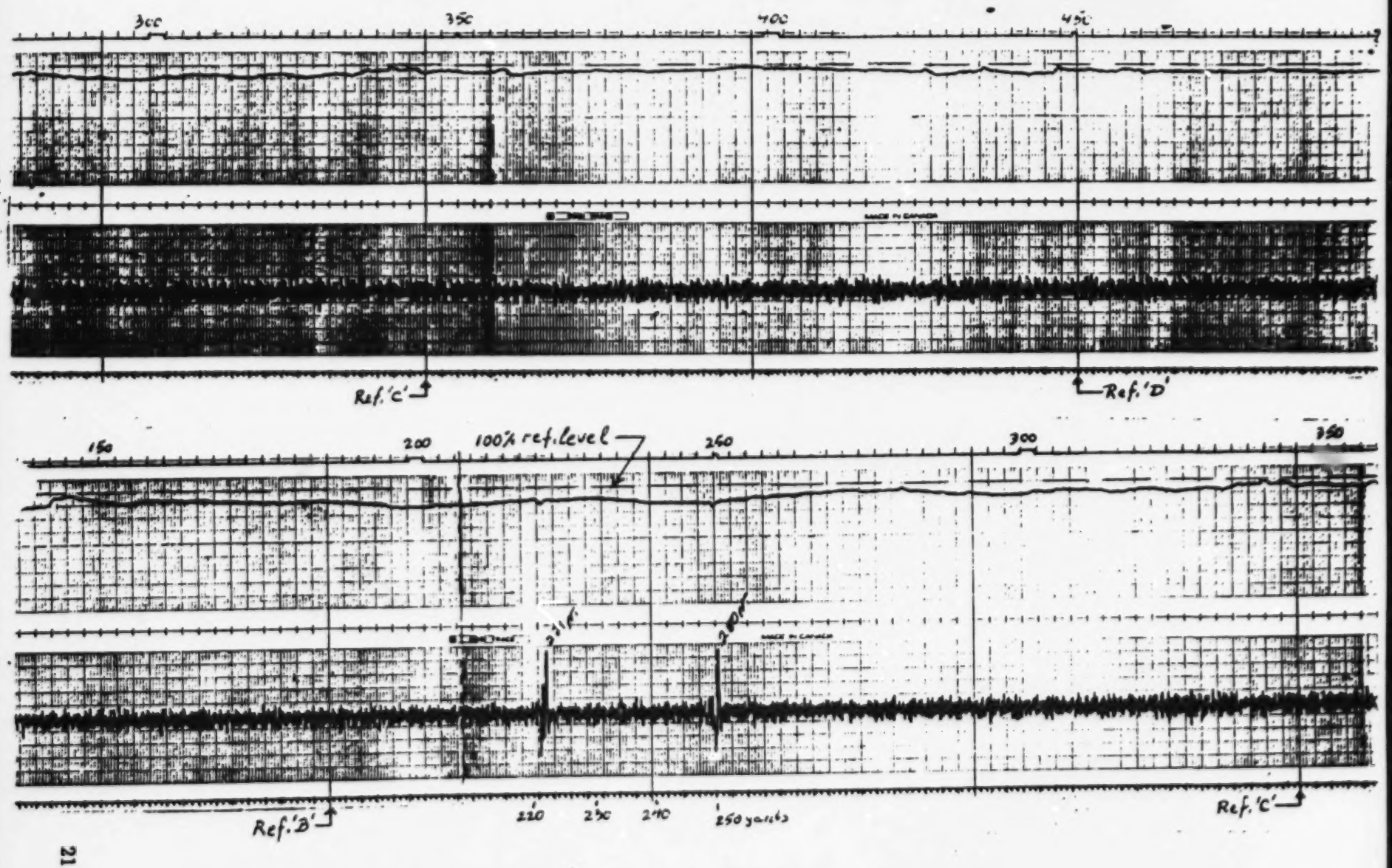

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Fig. 1d$_2$ (continued) — Rope PB3; 20.10.88 'second' Magnograph in situ test: chart re-spliced and marked by authors (662–749 yard segment at compartment #2 skip rope-end)

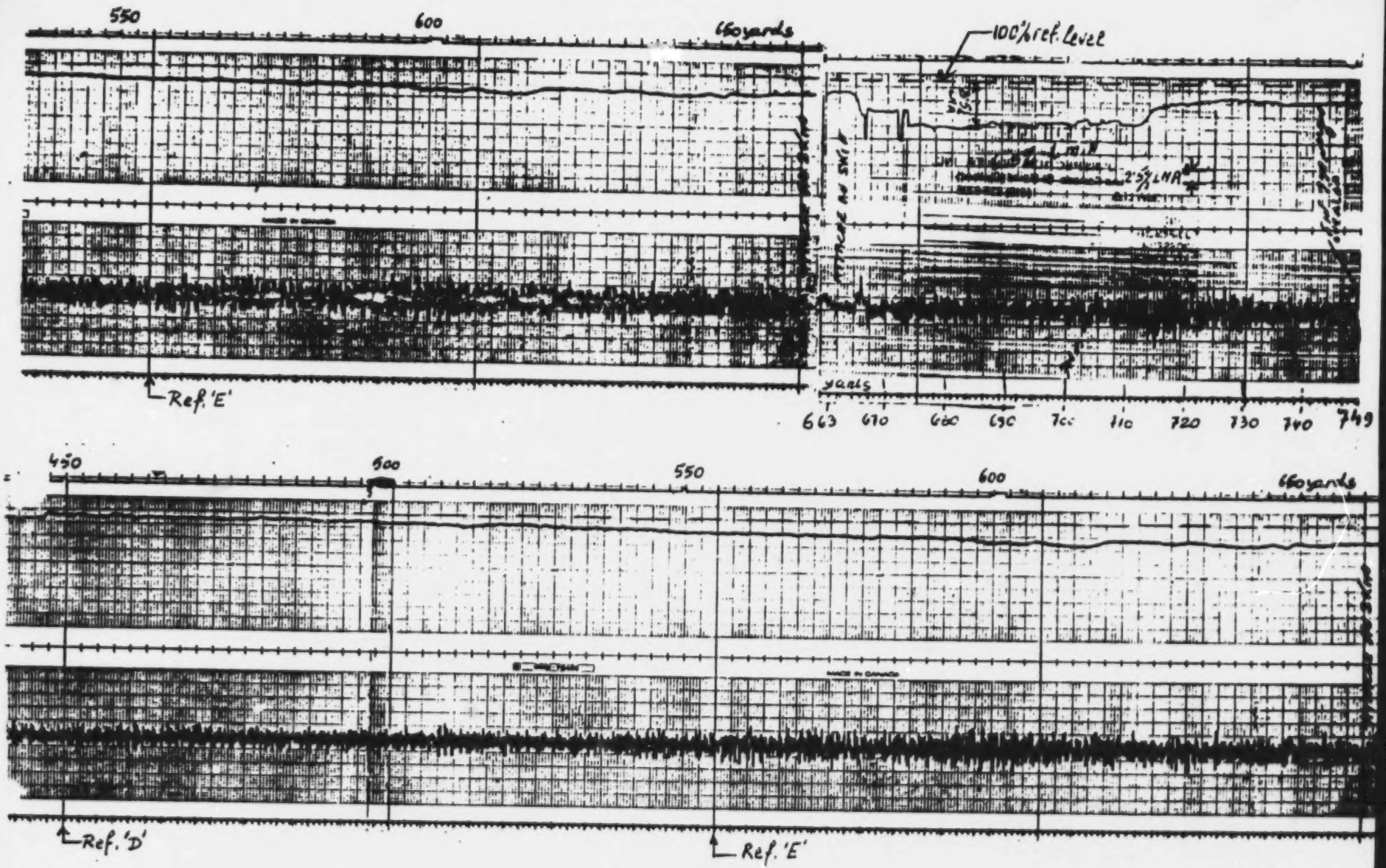

Fig. 1d$_2$ (continued) — Rope PB3; 20.10.88 'second' Magnograph in situ test: chart re-spliced and marked by authors (662–749 yard segment at compartment #2 skip rope-end)

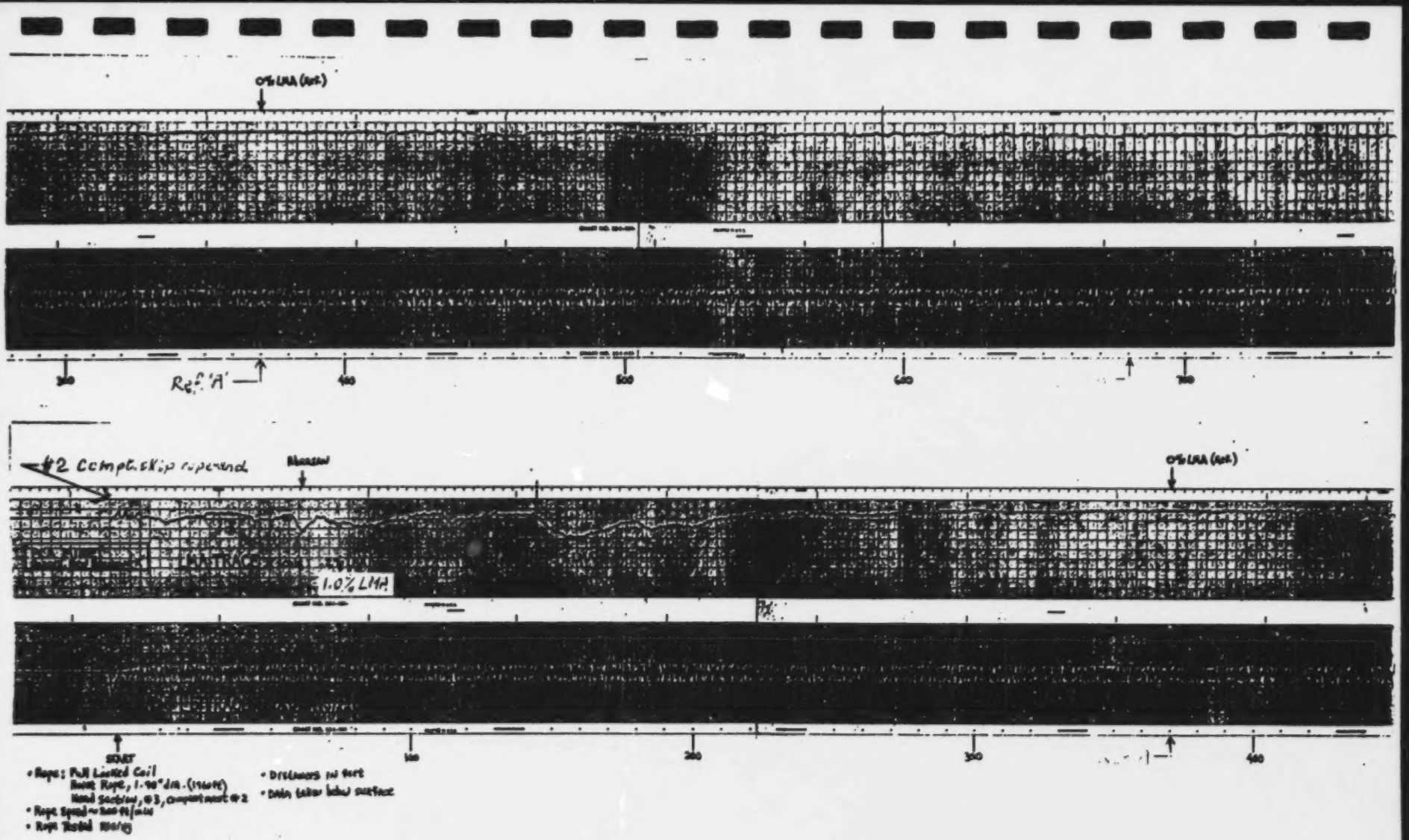

Fig. 2 — Rope PB3; 20.10.88 LMA-250 in situ test: operator's original strip-chart

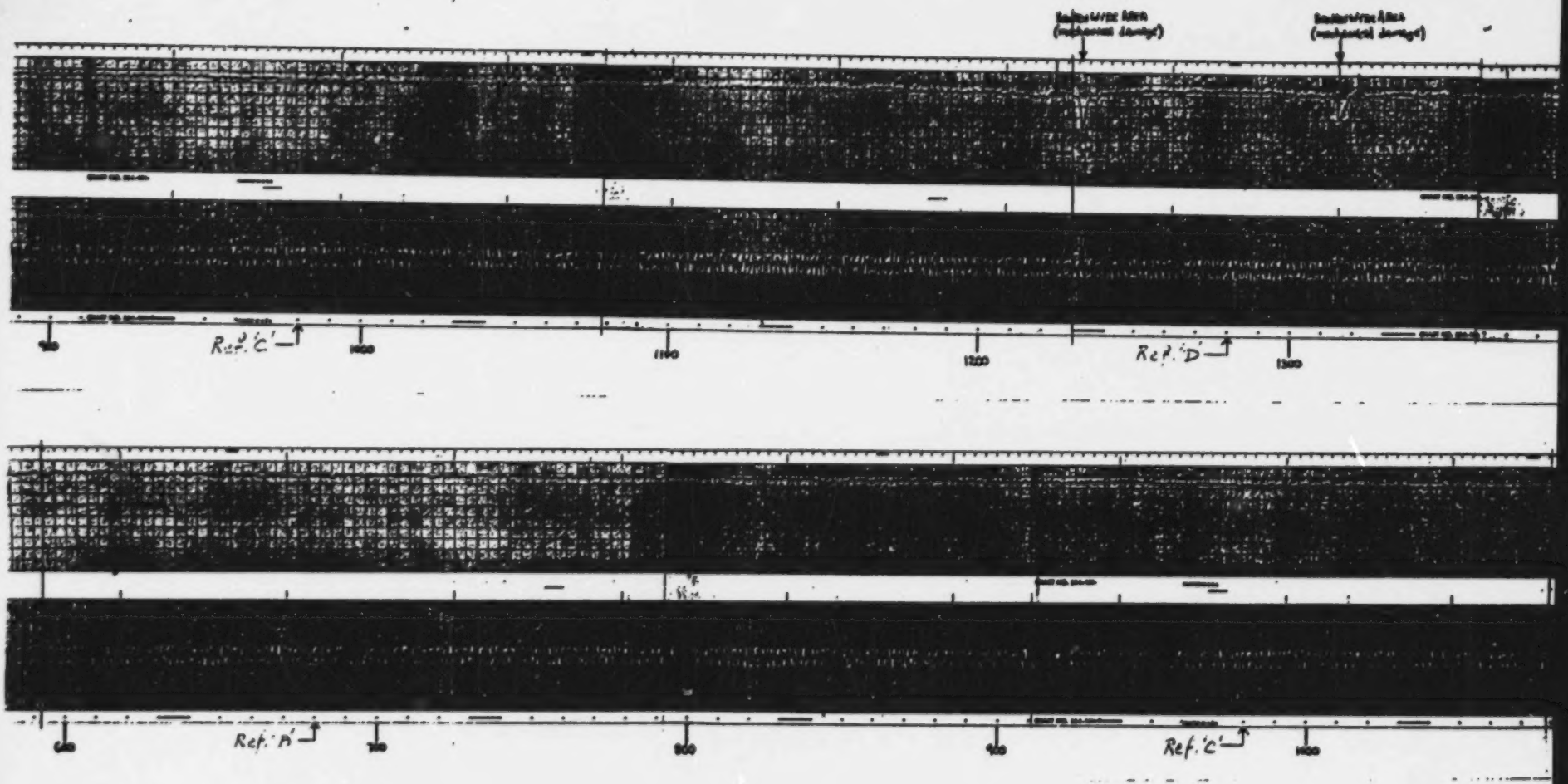

Fig. 2 (continued) — Rope PB3; 20.10.88 LMA-250 in situ test: operator's original strip- chart

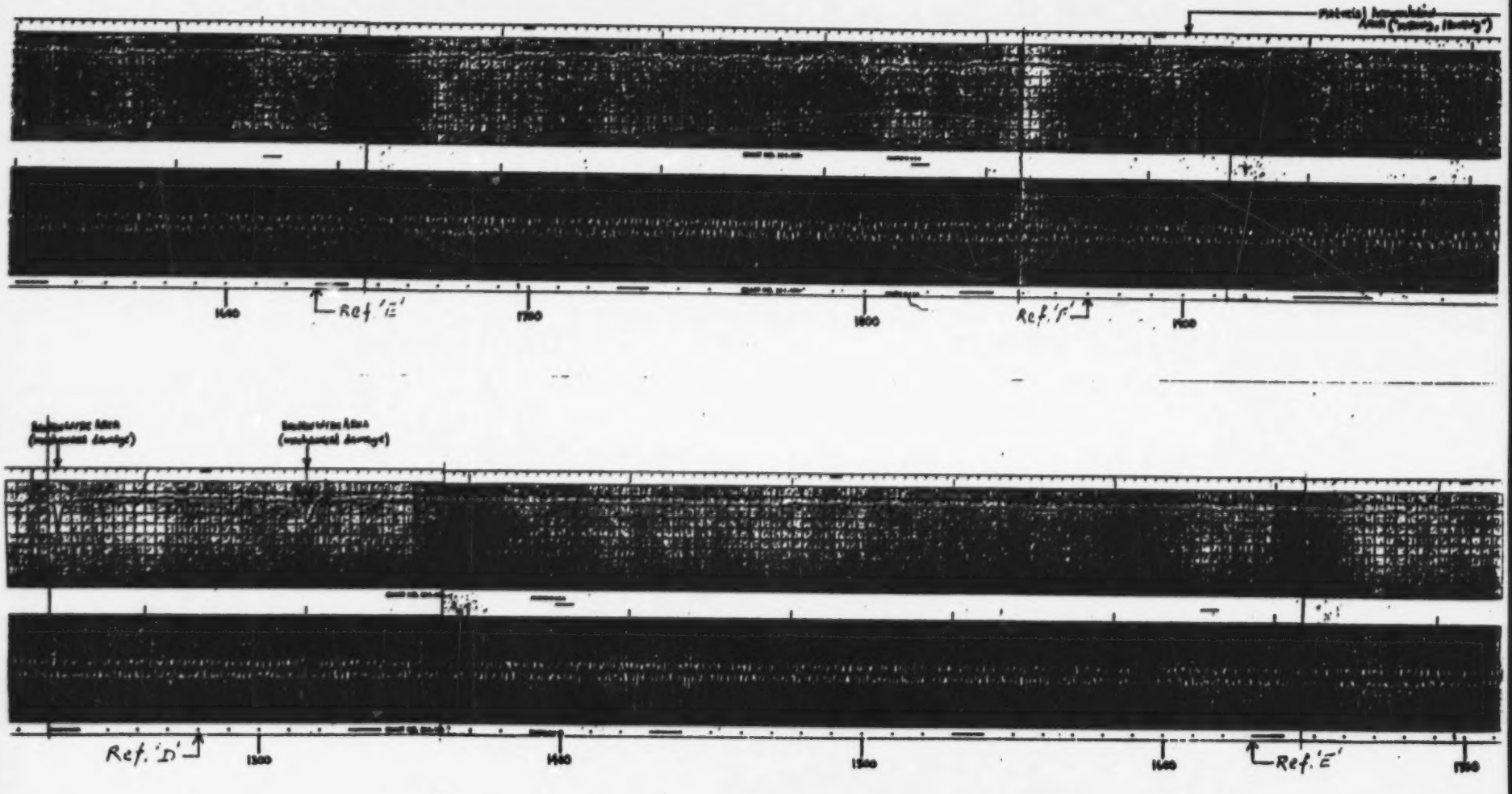

Fig. 2 (continued) — Rope PB3; 20.10.88 LMA-250 in situ test: operator's original strip- chart

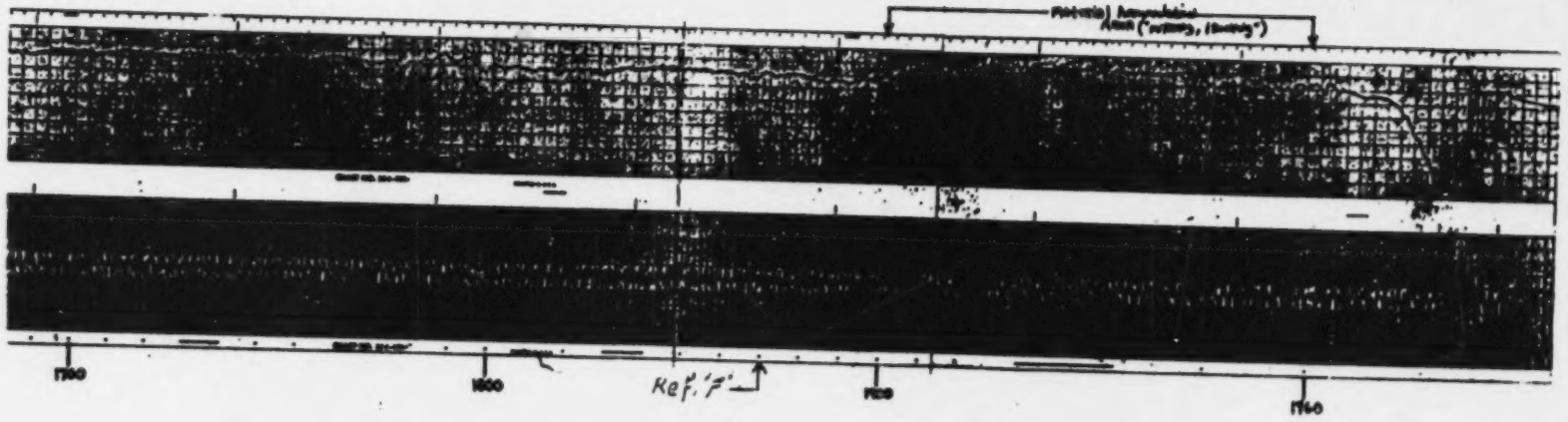

Fig. 2 (continued) — Rope PB3; 20.10.88 LMA-250 in situ test: operator's original strip-chart

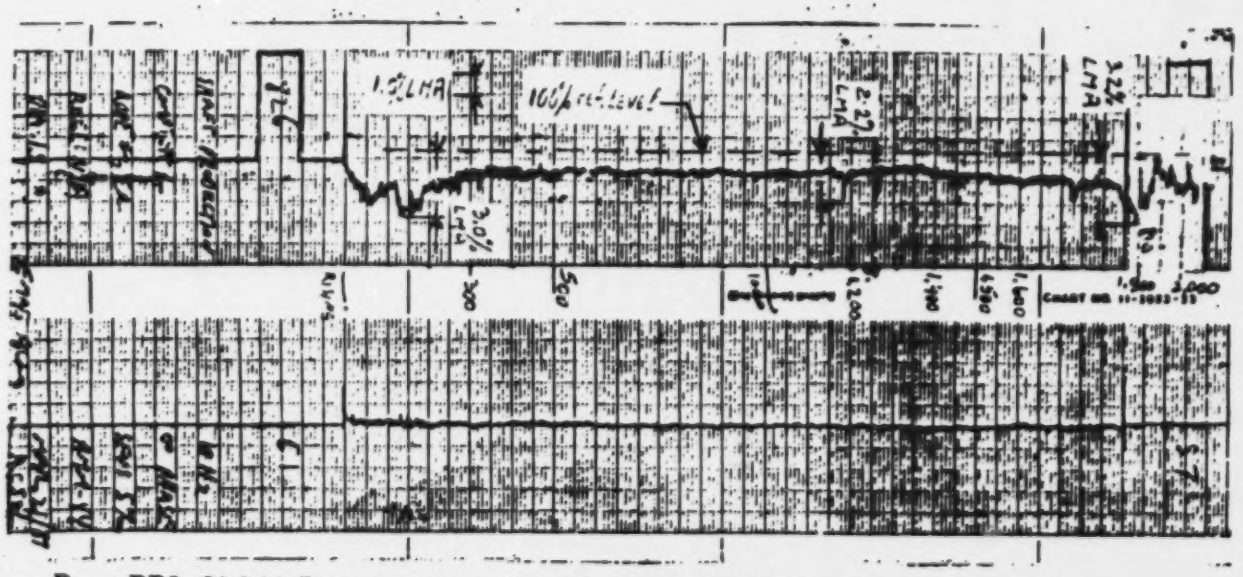

Fig. $3a_2$ — Rope PB3; 21.3.89 Rotesco AC in situ test: chart respliced and marked by authors

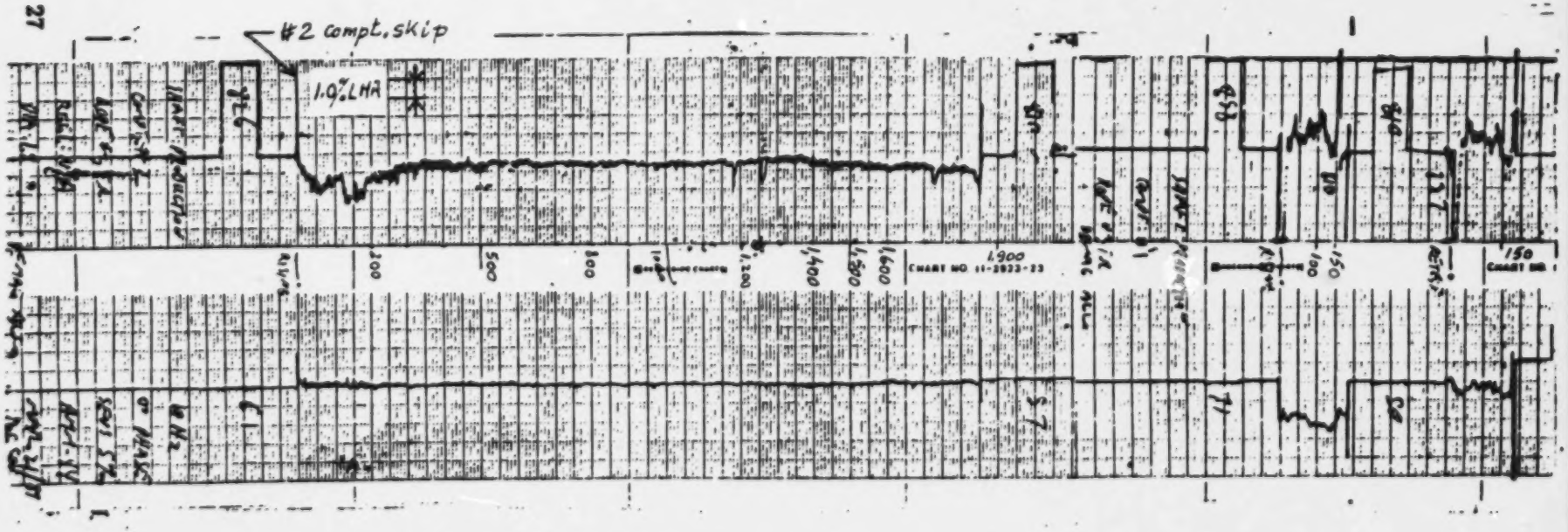

Fig. $3a_1$ — Rope PB3; 21.3.89 Rotesco AC in situ test: operator's original strip-chart

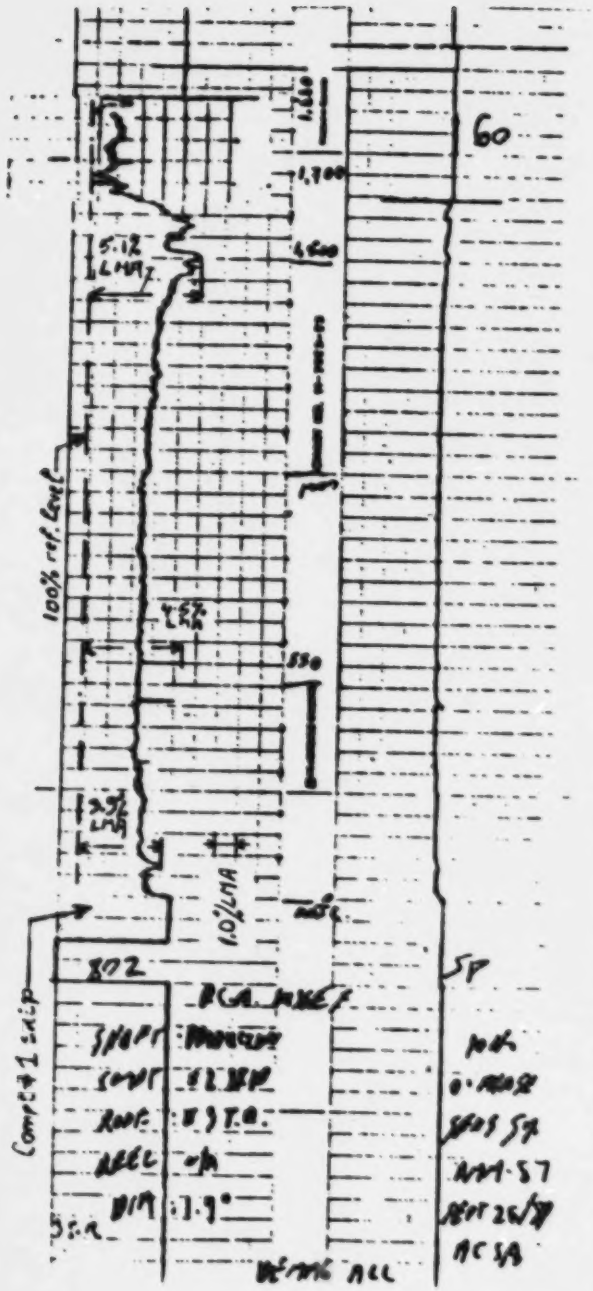

Fig. 3a$_4$ — Rope PB3; 26.9.89 Rotesco AC in situ test: chart respliced and marked by authors

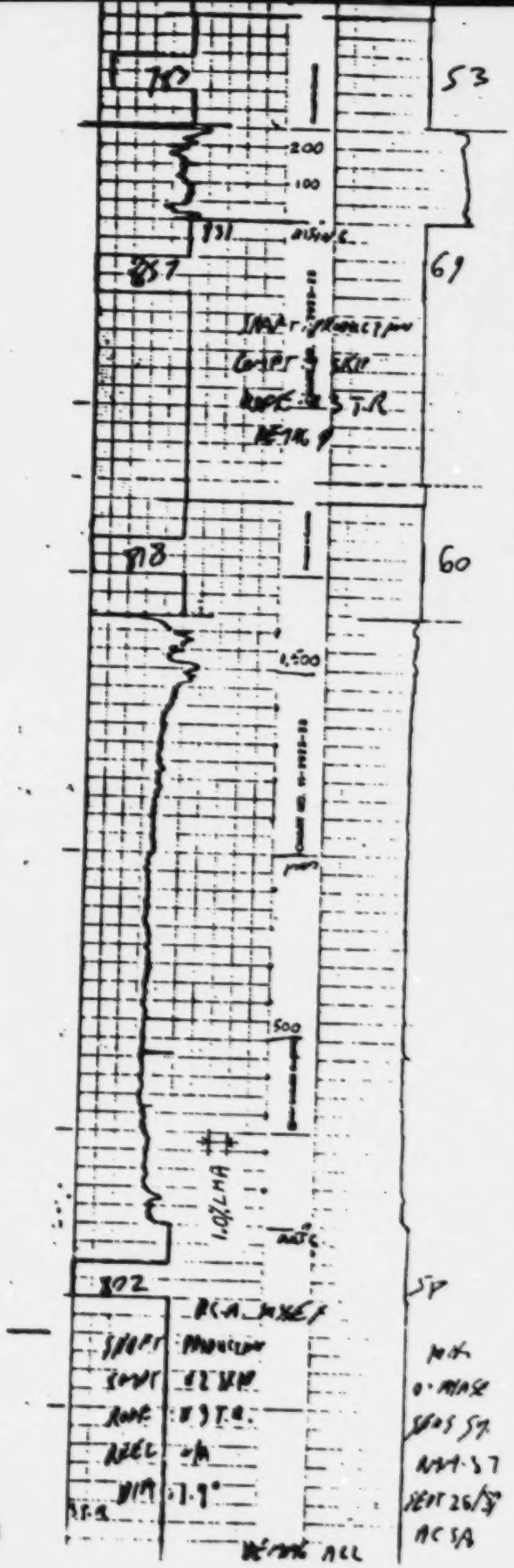

Fig. 3a$_5$ — Rope PB3; 26.9.89 Rotesco AC in situ test: operator's original strip-chart

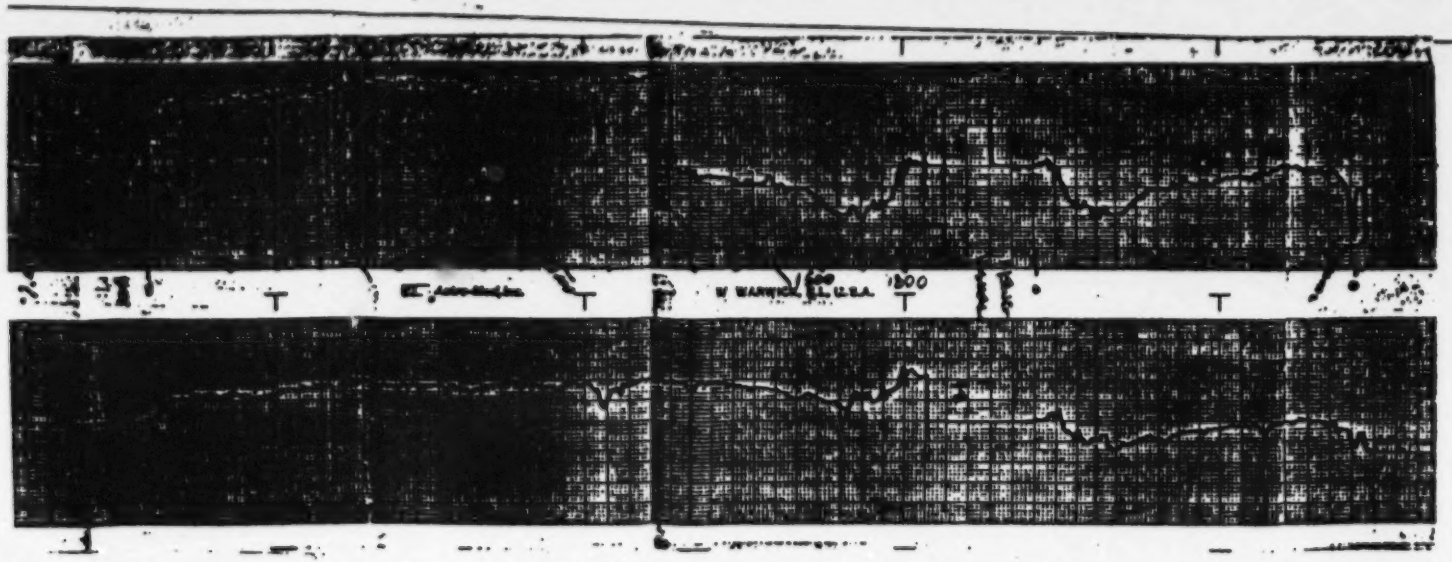

Fig. $3b_2$ — Rope PB3 (predecessor to our rope #7); 1.3.88 Rotesco AC in situ test @ 10.0% (F.S.) sensitivity: operator's original strip-chart

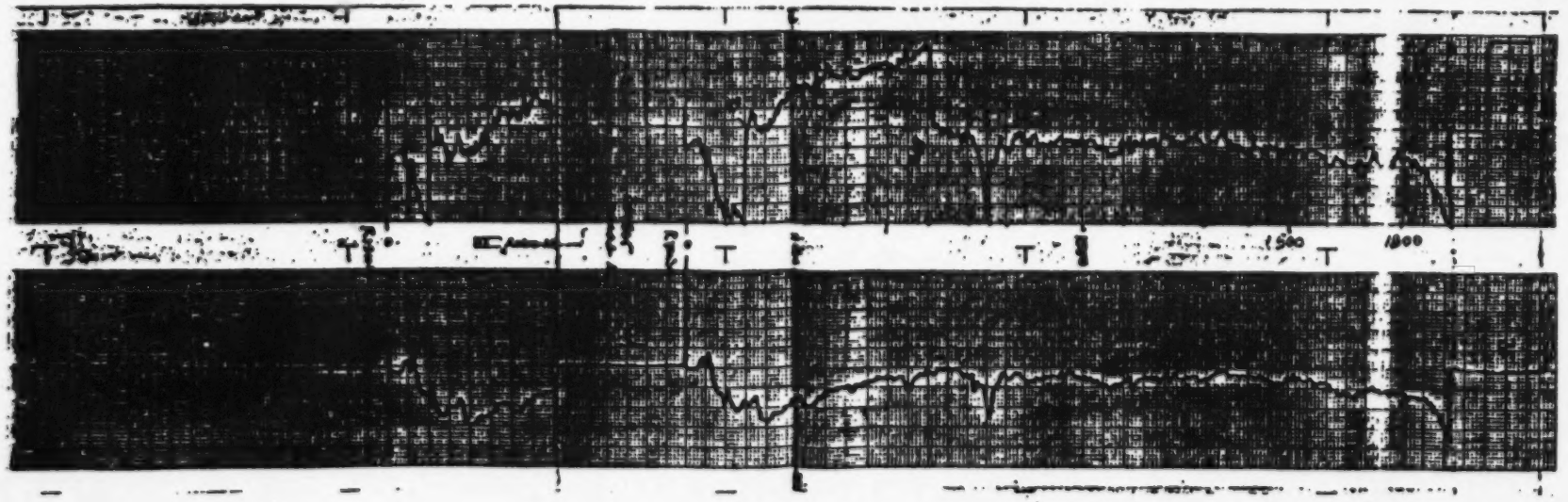

Fig. $3b_1$ — Rope PB3 (predecessor to our rope #7); 1.3.88 Rotesco AC in situ test @ 5.0% (F.S.) sensitivity: operator's original strip-chart

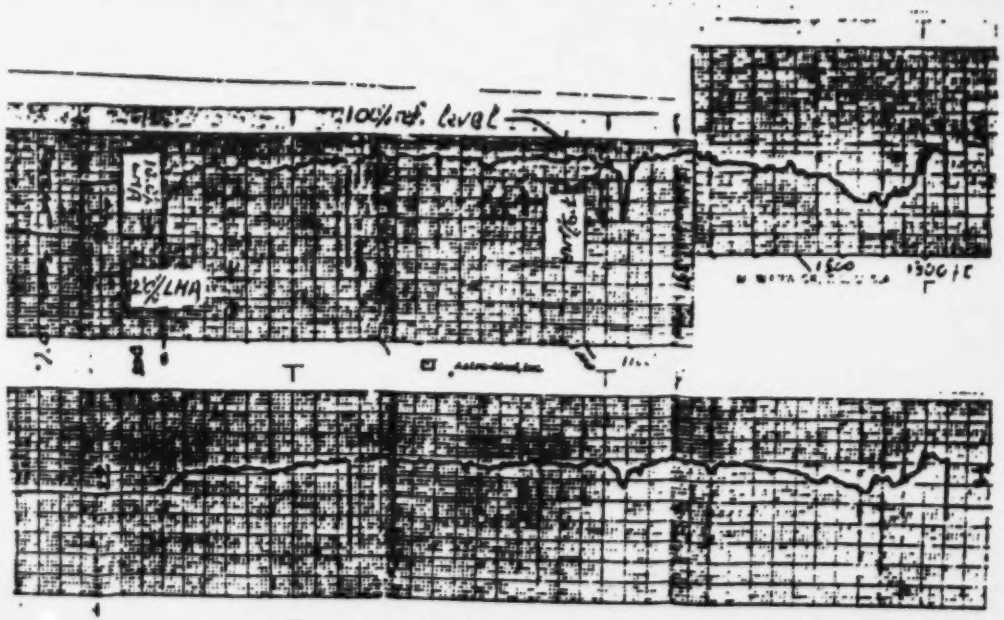

Fig. 3c$_2$ — Rope PB3 (predecessor to our rope #7); 1.3.88 Rotesco AC in situ test @ 10.0% (F.S.) sensitivity: chart respliced and marked by authors

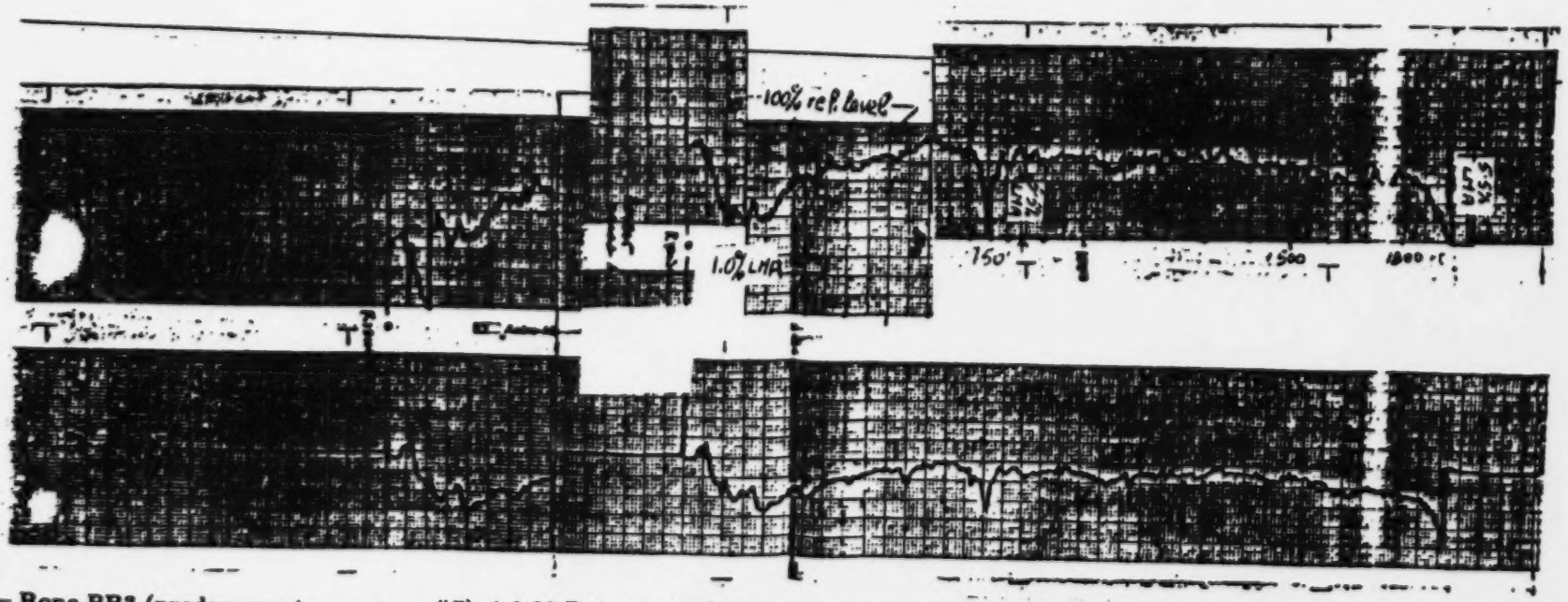

Fig. 3c$_1$ — Rope PB3 (predecessor to our rope #7); 1.3.88 Rotesco AC in situ test @ 5.0% (F.S.) sensitivity: chart respliced and marked by authors

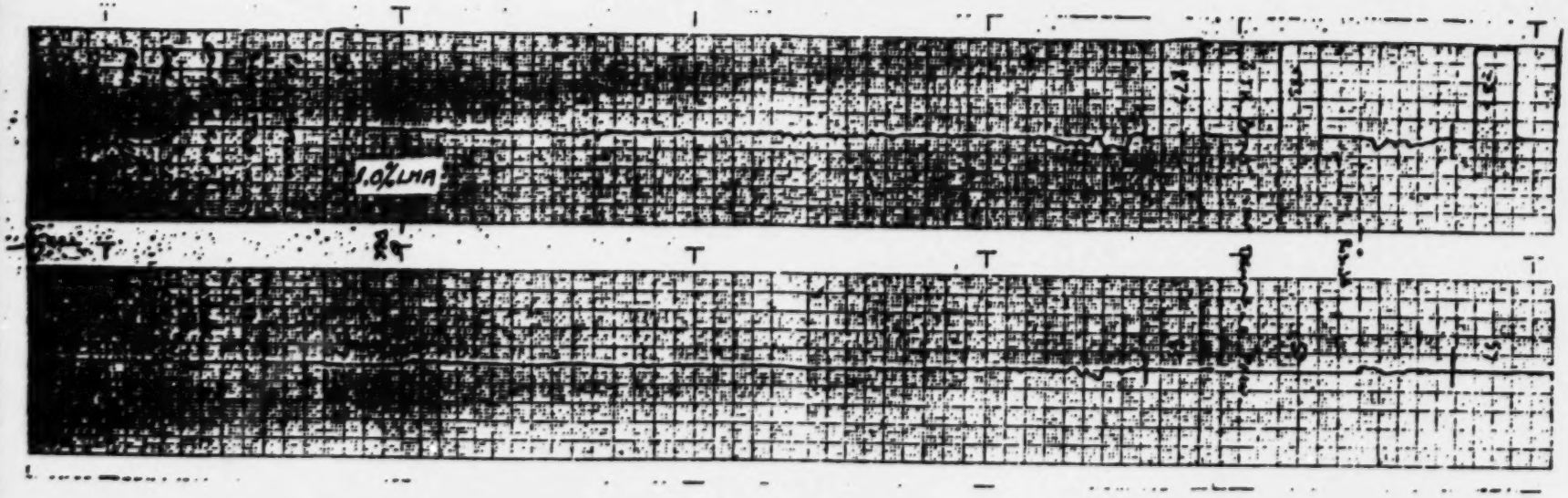

Fig. 3d — Rope PB2 (companion rope to our rope #7); 1.3.88 Rotesco AC in situ test: operator's original strip-chart

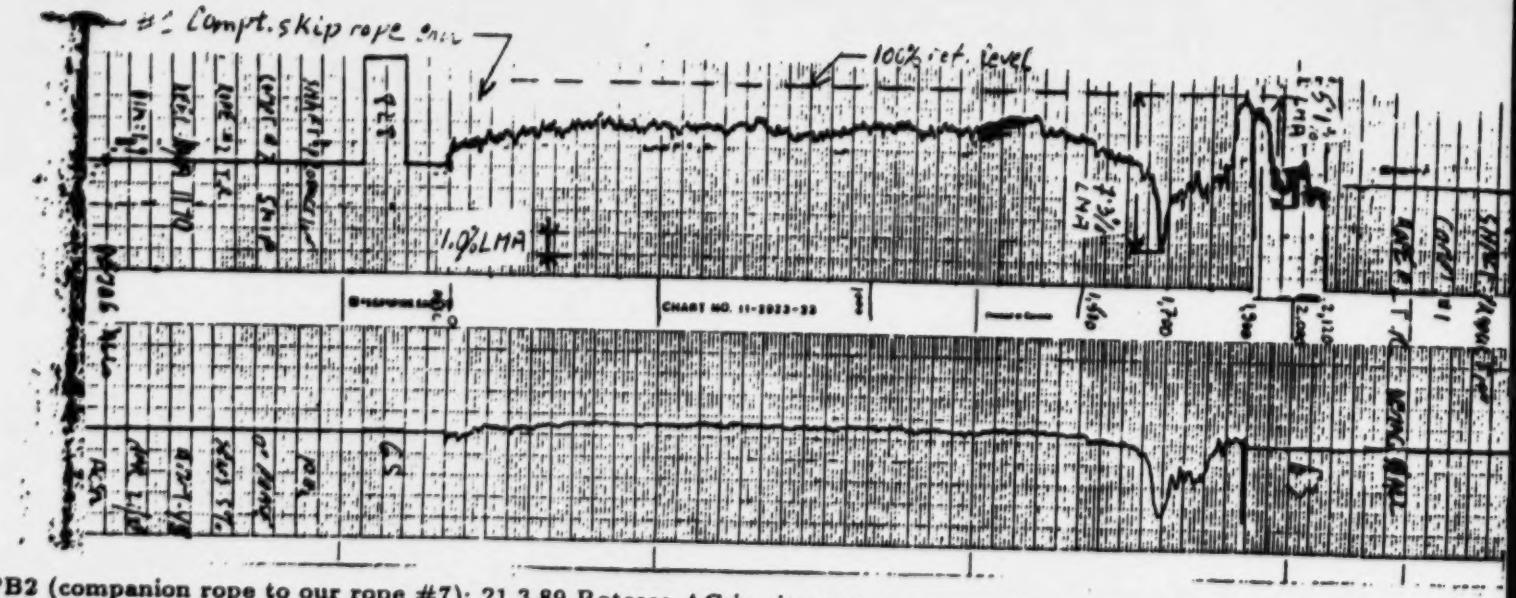

Fig. $3e_2$ — Rope PB2 (companion rope to our rope #7); 21.3.89 Rotesco AC in situ test: chart respliced and marked by authors

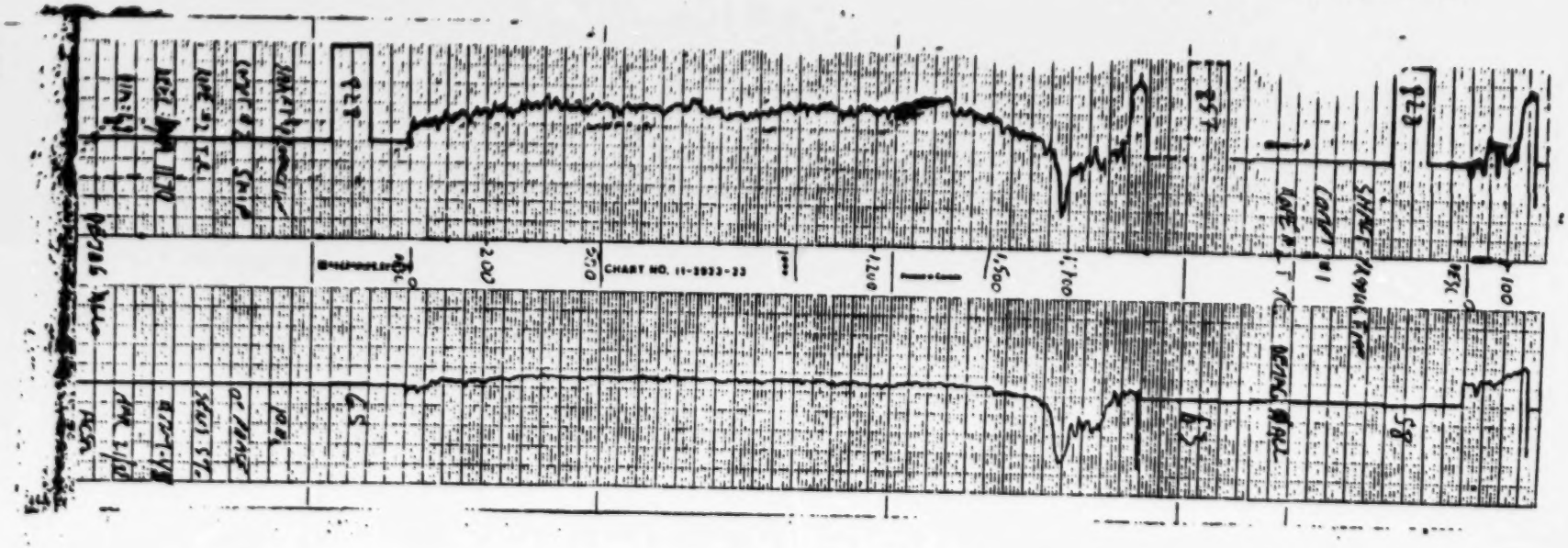

Fig. $3e_1$ — Rope PB2 (companion rope to our rope #7); 21.3.89 Rotesco AC in situ test: operator's original strip-chart